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The Rice Institute
Houston, Texas

Annual Progress Report
1952

N6onr-224 Task Order #3

Low Temperature
March 30, 1953

Annual Progress Report

1952

Contract N6onr-224 Task Order III

Low Temperature Physics

with

Office of Naval Research

Department of the Navy

Submitted March 30, 1953

Low Temperature Laboratory
The Rice Institute
Houston, Texas

Annual Progress Report

1952

Task Order III

Introduction

During the past year, research has continued on some of the subjects reported in the progress report for 1951. We have also continued work on projects begun under the direction of Professor Kurt Mendelssohn in the spring of 1952.

Reports of research completed during the year appear as reprints of the following papers:

1. Dielectric Constant in Perovskite Type Crystals
   by John H. Barrett, Phys. Rev. 86, 118 (1952) (Abstract)
2. Coexistence of Liquid Helium I and II
   by Philip Closmann and Richard T. Swim
   Phys. Rev. 86, 576 (1952).
3. Gyromagnetic Effect in a Superconductor
   by R. H. Pry, A. L. Lathrop, and W. V. Houston
   Phys. Rev. 86, 905 (1952).
4. Measurements on the Temperature, Current, Magnetic Field Phase Diagram of Superconductivity
   by K. Mendelssohn, C. Squire and Tom S. Teasdale
   Phys. Rev. 87, 589 (1952).
5. The Temperature Dependence of Electrical Resistance
   by W. V. Houston, Phys. Rev. 83, 1321 (1952) (Abstract)

The Following Letter to the Editor was published:

Note on Reflection and Diffraction from Ice Crystals in the Sky

by Charles F. Squire, J.O.A. 42, 782 (1952).

The following Letter to the Editor has also been submitted to the Physical Review:

The Paramagnetic Effect in Superconductors

by Tom S. Teasdale and H. E. Rorschach, Jr.

Two papers on current research were presented at the Thanksgiving meeting of the Physical Society held in St. Louis:

1. Flow of Helium II through Narrow Slits
   by Richard T. Swim

2. Frozen Moments in a Superconducting Sphere
   by Tom S. Teasdale

At the present time work is in progress on the flow properties of liquid Helium II, the nature of the superconducting state (particularly the intermediate state), and the elastic constants of Potassium Chrome Alum. The progress of this research is indicated by brief reports on each subject.

Respectfully submitted:

Harold E. Rorschach, Jr.

Harold E. Rorschach, Jr.
Project Supervisor

Abstracts

Dielectric Constant in Perovskite Type Crystals*

John H. Barrett
Rice Institute, Houston, Texas

Slater's theory of the dielectric constant in $BaTiO_3$ has been extended by treating the ionic polarizability quantum mechanically instead of classically. This leads to an expression for the dielectric constant which is good at all temperatures and shows a deviation from the Curie-Weiss law at low temperatures. The theory is applied to $SrTiO_3$ and to $KTaO_3$ above its transition at 13.2°K.

The Temperature Dependence of Electrical Resistance**

W. V. Houston
Rice Institute, Houston, Texas

The electrical resistance of a simple metal can be computed over a wide range of temperature by considering the thermal vibrations and the scattering from individual ions. Observations by MacDonald and Mendelssohn make possible a comparison with experiment from room temperature down to very low values. Moderate agreement for lithium and sodium can be obtained by a suitable choice of parameters, but the values necessary are not in close agreement with those suggested by other phenomena.

An approximate method for taking into account all three normal modes of vibration with a given propagation vector also gives moderate agreement with the observations.

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* Phys. Rev., 86, 118 (1952)

** Phys. Rev., 88, 1321 (1952)

Coexistence of Liquid Helium I and II

Philip Closmann and Richard T. Swim

Reprinted from The Physical Review, Vol. 86, No. 4, pp. 576–577, May, 15, 1952

Reprinted from THE PHYSICAL REVIEW, Vol. 86, No. 4, 576-577, May 15, 1952
Printed in U. S. A.

Coexistence of Liquid Helium I and II

PHILIP CLOSMANN AND RICHARD T. SWIM
Rice Institute, Houston, Texas
(Received March 31, 1952)

SINCE the transition between liquid helium I and liquid helium II is one of the second order, showing no latent heat, no phase boundary between the liquids can be expected. The two liquids can never be coexistent at any given value of temperature and pressure. However, both liquid forms can be present at the same time if one of the variables of state has a gradient within the space of observation. It seems that in none of the experiments on liquid helium carried out so far did a gradient of temperature or pressure covering the transition region exist, and it is, therefore, of interest to carry out such an experiment.

In view of the difficulty of establishing a pressure gradient, an arrangement involving a temperature gradient was chosen. This arrangement consisted of a thermally isolated column of helium. In this way the radial heat flow is zero, and one end could be at temperatures below the lambda-point, while the other end could be above the critical point. It is to be expected that in such an arrangement the main contribution to the heat transport will be provided by the liquid helium II. In view of the complex nature of this heat flow and also because of the inversion of the thermal expansion at the lambda-point, the question of the temperature distribution cannot, however, be solved through mathematically rigorous procedures.

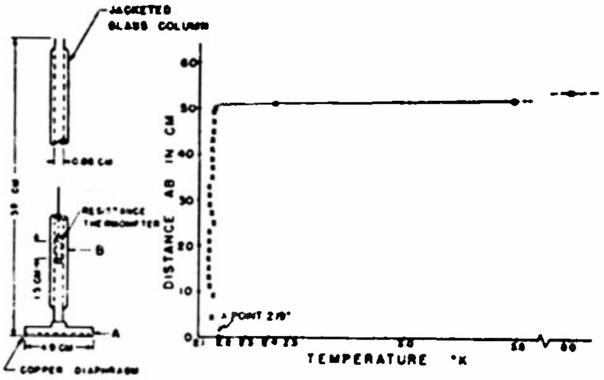

FIG. 1. Diagram of the apparatus and experimental results on liquid helium I and II.

The apparatus (see Fig. 1) consisted of a vertical glass tube 55 cm long and 0.86-cm diameter which was enclosed in a vacuum jacket. The tube was thermally connected by means of copper-glass seals to a container with liquid nitrogen at the upper end and a bath of liquid helium II at the lower end. The whole arrangement was placed into a Dewar vessel which contained liquid helium II at the bottom and a metal reservoir with liquid nitrogen at the top. In this way the influence of radiation can be neglected. The tube could be filled with helium at more than the critical pressure, and the temperature at any place in it determined by a small resistance thermometer which could travel through the length of the tube. This temperature probe consisted of a hollow Lucite cylinder carrying on its outside a coiled resistance wire of leaded brass. Care was taken to make the heat resistance of the metal partition between the helium in the tube and that in the outer bath small enough to allow for a temperature below the lambda-point inside the lower end of the tube.

The results show that at pressures above 2.2 atmospheres and under equilibrium conditions, practically the whole of the tube was full of liquid helium II, leaving only about 4 cm at the top of the tube for the temperature gradient between 2.16°K and 80°K. The exact point where the liquid helium II ended was indeterminate to the extent of 1.5 cm, this being the length of the thermometer. As expected, the transition region between liquid helium II and liquid helium I as well as between liquid helium I and the gas showed no phase boundary or any other anomalous optical properties. However, on releasing the pressure slightly below the critical value, critical opalescence and subsequently the appearance of a meniscus was observed in this region. Prior to these observations when helium was being introduced into the tube, it was noted that the evaporation of liquid from the pumped helium II bath increased rapidly because the tube containing liquid helium II and reaching up into the Dewar vessel constituted a very good heat conductor. This fact is of importance for the design of cryogenic apparatus, showing that tubes reaching from higher temperatures into a bath of liquid helium II and containing helium of more than critical pressure will constitute a very serious heat leak.

The authors wish to thank Professor Kurt Mendelssohn, F.R.S., for suggesting the problem and directing the research during his visit at The Rice Institute. The advice and assistance of Professor C. F. Squire is also acknowledged.

Gyromagnetic Effect in a Superconductor

R. H. Pry, A. L. Lathrop, and W. V. Houston

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Gyromagnetic Effect in a Superconductor

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Rice Institute, Houston, Texas
(Received February 15, 1952)

The gyromagnetic ratio of a superconducting tin sphere has been measured by the Einstein-DeHaas method. The result is approximately that to be expected on the picture of perfectly free superconducting electrons and is in agreement with the work of Kikoin and Gubar.

I. INTRODUCTION

For pure solid superconducting materials, Meissner and Ochsenfeld[1] have shown that the magnetic induction B inside the metal is zero. This implies either perfect diamagnetism or large surface currents in the presence of a magnetic field. In either case, the gyromagnetic effect for a superconductor should be observable.

The gyromagnetic effect has been most satisfactorily observed by the Einstein-DeHaas method. This method uses a torsion pendulum made of the magnetic material and such that a change of magnetization causes a torque and a change in angular momentum.

Kikoin and Gubar[2] carried out just such an experiment on a small superconducting lead sphere. They drove their torsion pendulum with the impulses produced by reversing a vertical magnetic field at the resonant frequency. They calculated the magnitude of these angular impulses from the resulting steady-state amplitude of the system; and in turn they determined that the ratio of the magnetic moment to the mechanical moment of the superconductor was the same as it would be in ordinary diamagnetic materials with a magnetization arising from orbital electron motions alone.

As has been shown by Meissner,[3] the model of perfect diamagnetism used by Kikoin and Gubar gives the same gyromagnetic effect as the picture of surface currents given by the London theory. According to the London picture,[4] the changing magnetic field acts on the positive charge which remains when the superconducting electrons are disregarded. The experiment then serves to measure the product of this positive charge density and the square of the penetration depth.

The report of Kikoin and Gubar did not make completely clear the direction of the effect. Since the electrons go in one direction, and the material sphere, which is observed, goes in the opposite direction rather than being dragged along by the electrons, it is important that this direction be unambiguous. We have therefore repeated their gyromagnetic experiment with a superconducting sphere to demonstrate again both the magnitude and the direction of the effect.

[1] W. Meissner and R. Ochsenfeld, Naturwiss. 21, 787 (1933).
[2] I. K. Kikoin and S. W. Gubar, J. Phys. USSR 3, 333 (1940).
[3] W. Meissner, Sitz. Bayerischen Acad. p. 321, November, 1948.
[4] F. London, Physica 3, 458 (1936); and *Superfluids* (John Wiley & Sons, Inc., New York, 1950).

II. EXPERIMENTAL APPARATUS AND PROCEDURE

Figure 1, shows the details of the experimental equipment. The torsion fiber is a tungsten wire 75 cm long and 0.003 in. in diameter, and is kept at room temperature. To the bottom of the fiber is attached an octagonal Lucite cylinder. On each of the eight faces is a front surface mirror about 1 cm^2 in area. The connection between the Lucite cylinder and the tin sphere is made with a glass tube. The tin sphere is one inch in diameter with variations of less than 0.0004 in., and is made from spectroscopically pure tin supplied by Johnson-Mathey Company, London. The sphere is in contact with the helium vapor, but not in contact with the liquid helium. The Helmholtz coils shown are used to neutralize the horizontal component of the earth's field.

The switching of the solenoid current was controlled by a phototube and two-stage, directly coupled dc amplifier which actuated a mechanical relay. A separate contact on the relay was used to shunt out, on alternate half-cycles, a part of the plate resistance of the phototube, in order to compensate for the difference between the pull current and release current of the relay. This arrangement minimized the errors in switching time which otherwise would have occurred. The time for complete field reversal was less than 3×10^{-3} sec corresponding to less than one six-thousandth of the period of the pendulum.

The earth's field was neutralized and the solenoid field made vertical by adjustments similar to those outlined by Kikoin and Gubar. Precision was obtained by using a torsion pendulum with a one-inch magnetized iron sphere of known magnetic moment.

The amplitude and period of the oscillations were measured by observing a hairline focused on a scale 12.5 meters from the torsion pendulum.

When cooling the tin sphere through the transition temperature the earth's field was neutralized and the sphere was set into oscillation with a large amplitude. This oscillation tended to minimize further any possible frozen in moment.[5]

[5] Alers, McWhirter, and Squire, Phys. Rev. 84, 104 (1951).

III. EXPERIMENTAL RESULTS

The results of the experiment confirm those of Kikoin and Gubar. The directions of the angular impulses are the same as one would observe if the effect were that of Faraday induction operating on a sphere composed of positive ions. Referring to Fig. 1, when the sphere is rotating in the clockwise direction as viewed from above, the field shifts from the down direction to the up direction as the oscillator passes through center. Under these switching conditions, Fig. 2 shows the approach to the steady-state condition with driving fields of 100 gauss or 10^{-2} weber/m^2 (curve A) and 51 gauss or 0.51×10^{-2} weber/m^2 (curve B). Just below these curves the zero field case (curve C) is plotted. Curve D shows the effect of reversing the cycling of the switching in the case of the larger field. Also, for the larger field, the approach to the asymptote was made from the low amplitude side, but these points are not included in the figure.

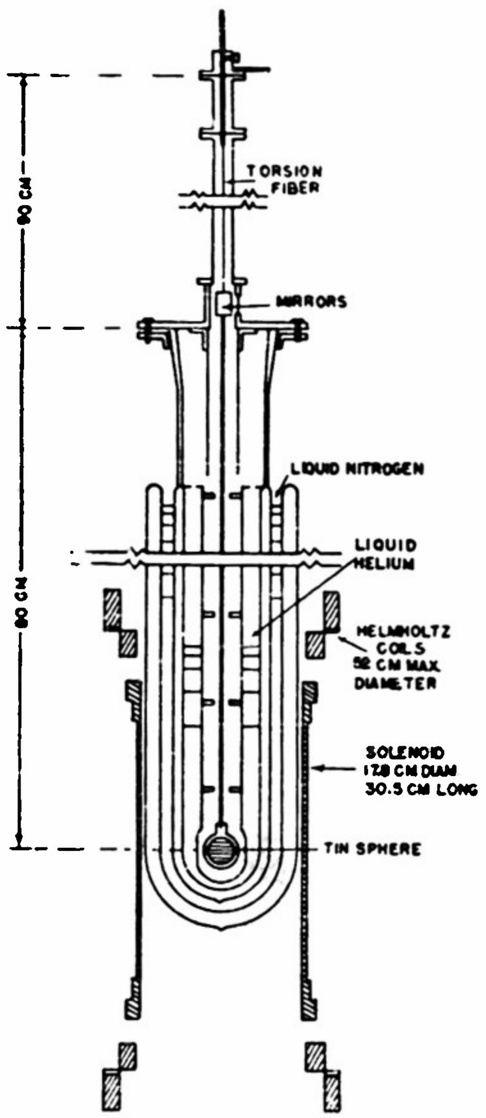

FIG. 1. Schematic outline of the cryostat and torsion pendulum.

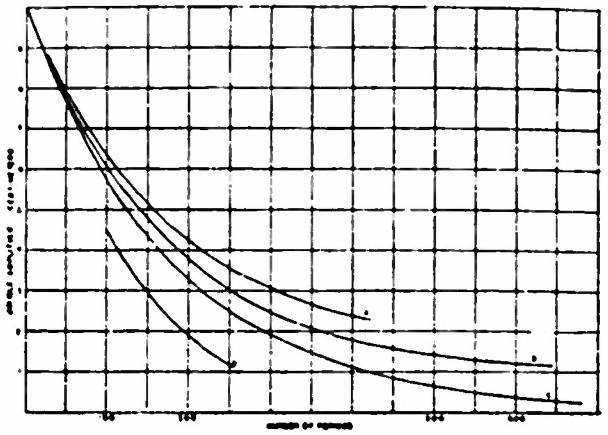

FIG. 2. Decay of the amplitude of vibration toward the limiting values.

The experimental curves show an asymptotic approach to a double amplitude of 0.95 cm at 0.51×10^{-2} weber/m^2 and 1.65 cm with 10^{-2} weber/m^2.

The observed value may be compared with the results of a simple calculation based on consideration of the impulse and momentum change of the damped oscillator.

In the steady state the system behaves like a damped oscillator for $\frac{1}{2}$ cycle. It then receives an angular impulse which just makes up for the frictional loss of the absolute value of the momentum. This frictional loss of momentum is equated to the angular impulse given the oscillator because of the magnetic field change from $+B$ to the value $-B$. The equation of motion for $\frac{1}{2}$ period is

$$\theta=\theta_0 e^{-\delta t}\cos wt,$$

with momentum: $I\dot{\theta}=-I\theta_0(we^{-\delta t}\sin wt+\delta e^{-\delta t}\cos wt)$, where the moment of inertia $I=69.4\times10^{-7}$ kg m^2 and the measured value of $\delta=2.67\times10^{-4}$ sec^{-1}. The loss in momentum in one half-period occurs in the time interval $-\pi/2w$ to $+\pi/2w$, so that the momentum change is

$$\Delta|P|=-I\theta_0\delta\pi+\text{small terms.}$$

Further detailed analysis shows that the steady state is approached exponentially and that the maximum amplitude of the nth oscillation θ_n is given by

$$\theta_n=\theta_0+Ae^{-2\pi n\delta/w}.$$

In the magnetic field B the sphere has a magnetic moment[4]

$$M=2\pi R^3B/\mu_0,$$

so that switching the field from $+B$ to $-B$ causes a change of magnetic moment $4\pi R^3B/\mu_0$. Then the change of angular momentum must be $(2m/e)(4\pi R^3B/\mu_0)$, if $2m/e$ is taken to be the ratio between the angular momentum and the magnetic moment.

Equating the frictional loss of momentum to the gain from the field change, we get a steady-state angular amplitude:

$$\theta_0=(2m/e)(4\pi R^3B/\mu_0)(1/I\delta\pi)=3.87\times10^{-2}B\text{ radian,}$$

where B is expressed in webers/m^2.

This angular momentum is that of the superconducting electrons, but since the total angular momentum around the vertical axis does not change, the angular momentum of the positive ions and remaining electrons composing the sphere must change in just the opposite sense and by the same amount. It is this latter change that is observed.

Another way of looking at this phenomenon was suggested by Meissner.[3] The magnetic field penetrates only a short distance below the surface of the sphere, but as it changes, an electric field is present, which acts both on the superconducting electrons and on the remaining positive ions. Since the superconducting electrons do not drag the ions with them, the two systems move independently with equal and opposite angular momenta. The motion of the positive ions is the one observed by the experimental arrangement used.

IV. DISCUSSION OF ERRORS

In spite of much care the tin sphere had a slightly ellipsoidal character, the field was not exactly uniform over the volume of the sphere, and the switching of the magnetic field did not always occur precisely at the same point. In zero field a certain rest point or zero point about which the oscillator swung was noted. With a steady upward vertical field of 10^{-2} weber/m^2, the zero point shifted 0.3 mm to the right on the scale corresponding to 1.2×10^{-5} radian of angle. With a steady downward vertical field of the same amount, the zero point shifted 0.9 mm to the right. These errors might be further reduced with greater effort should greater accuracy justify such action, but differences between the experimental and expected values may be attributed to these experimental errors.

V. CONCLUSION

The experiments gave rough agreement with the theory as to the magnitude of the effect. The result was 15 percent low for the 10^{-2} weber/m^2 driving field and 4 percent low for the 0.51×10^{-2} weber/m^2 driving field. The direction of driving torque was such as to produce an angular impulse on the superconducting sphere just as if the Faraday induction were operating on the positive ion lattice.

The authors are greatly indebted to the constant assistance of Professor C. F. Squire. One of us (R.H.P.) held the Shell Fellowship during this work.

Measurements on the Temperature, Current, Magnetic Field Phase Diagram of Superconductivity

K. MENDELSSOHN, C. SQUIRE, AND TOM S. TEASDALE

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Measurements on the Temperature, Current, Magnetic Field Phase Diagram of Superconductivity

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Rice Institute, Houston, Texas

(Received April 14, 1952)

Experiments have been carried out to investigate the existence of a paramagnetic effect, reported by other workers, at the transition to superconductivity. While, in the other experiments, the induction in the sample was measured during changes of the magnetic field, the work described in the present paper deals with induction measurements at constant values of magnetic field, current, and temperature. The transition region of tin was investigated by separately varying, stepwise, each of these three parameters. With the current of 10 amperes used in our experiments, no paramagnetic effect was observed anywhere in the transition region.

INTRODUCTION

SINCE the discovery, in 1933, by Meissner and Ochsenfeld, that superconductivity is accompanied by zero magnetic induction ($B=0$), it has generally been assumed that, as the metal becomes superconductive, its susceptibility becomes strongly diamagnetic. Numerous experiments in which the temperature or the magnetic field were changed have, indeed, confirmed this view. However, in 1943, Steiner and Schoeneck[1] reported observations indicating a paramagnetic susceptibility which preceded the change to diamagnetism. This effect occurred only when the destruction of superconductivity was carried out simultaneously by a magnetic field in the longitudinal direction and a current in the same direction. It was pointed out by one of us[2] that the observed increase in induction might possibly have been only an apparent one, because only the flux in the longitudinal direction was measured. Similar experiments have recently been performed by Meissner, Schmeissner, and Meissner,[3] who also observed paramagnetic effects of the same nature. In these experiments, the changes of flux were measured which occur in the specimen when the magnetic field was reversed, while at the same time a steady current was passing through the specimen.

Since in all this work the observation of a paramagnetic effect was coupled with a simultaneous variation of one of the variables of state (the magnetic field), it is clearly desirable to investigate whether there actually exist, in the transition, definite values of magnetic field, current, and temperature, for which the susceptibility of a superconductor is paramagnetic. Assuming the validity of Silsbee's hypothesis, a three-dimensional diagram of state can be constructed (Fig. 1), with the temperature, the magnetic field, and the current as dependent variables. The volume inside the T, H, I, surface represents the superconducting state, and that outside represents the normal state. The transition to superconductivity can be effected in three different ways, as is indicated by the arrows. It was decided, therefore, to carry out measurements of the induction in the longitudinal direction of a long cylinder of tin, at fixed values of magnetic field, current, and temperature, in the transition region. The experiments were carried out in such a way that two variables were held constant throughout, while the third one was changed in small steps in the way indicated by the arrows in Fig. 1.

METHOD

The method consists in moving an induction coil along a cylindrical specimen, which is aligned in the direction of a homogeneous magnetic field. The cylinder is made up of rods of copper, tin, and lead, in series, and the coil can be moved from the center of the tin rod to the center of the lead rod or of the copper rod. Since in the transition region of tin (3.7°K) lead is superconductive and copper is nonsuperconductive, the movement of the coil will compare the flux in the tin rod, at constant field, current, and temperature, with the flux through a superconductive or a normal rod of identical dimensions.

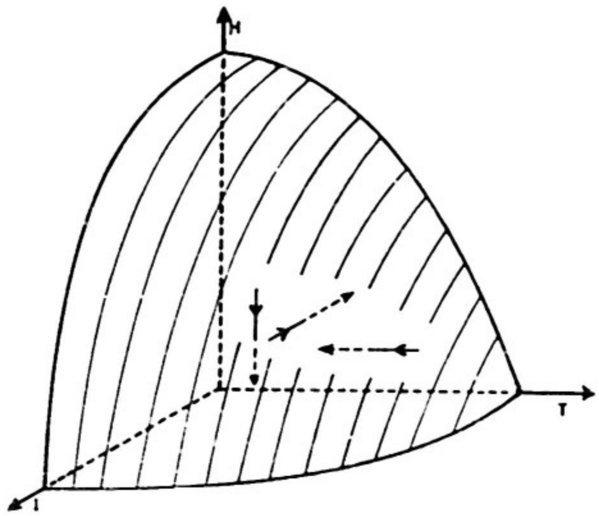

FIG. 1. The T, H, I, surface, separating the normal and the superconducting phases.

* Visiting Professor from Oxford University, Oxford, England.
[1] K. Steiner and H. Schoeneck, Physik. Z. 44, 346 (1943).
[2] K. Mendelssohn, Repts. Prog. Phys. 10, 358 (1946) (London: Physical Society).
[3] Meissner, Schmeissner, and Meissner, Z. Physik 130, 521 (1951).

Figure 2 shows the apparatus with the induction coil, C, which is connected to a ballistic galvanometer, so that the deflections of the galvanometer are proportional to the changes of total flux through the coil. The coil moves from one position around the specimen to another.

The specimen, S, consists of lengths of 8 cm each of lead, tin, and copper cylinders, soldered together in series in a thin German silver tube. The diameter of the metal samples is 2.8 mm. The rod is mounted vertically, with the upper end (copper) held in a textolite block, B. The sample holder is suspended

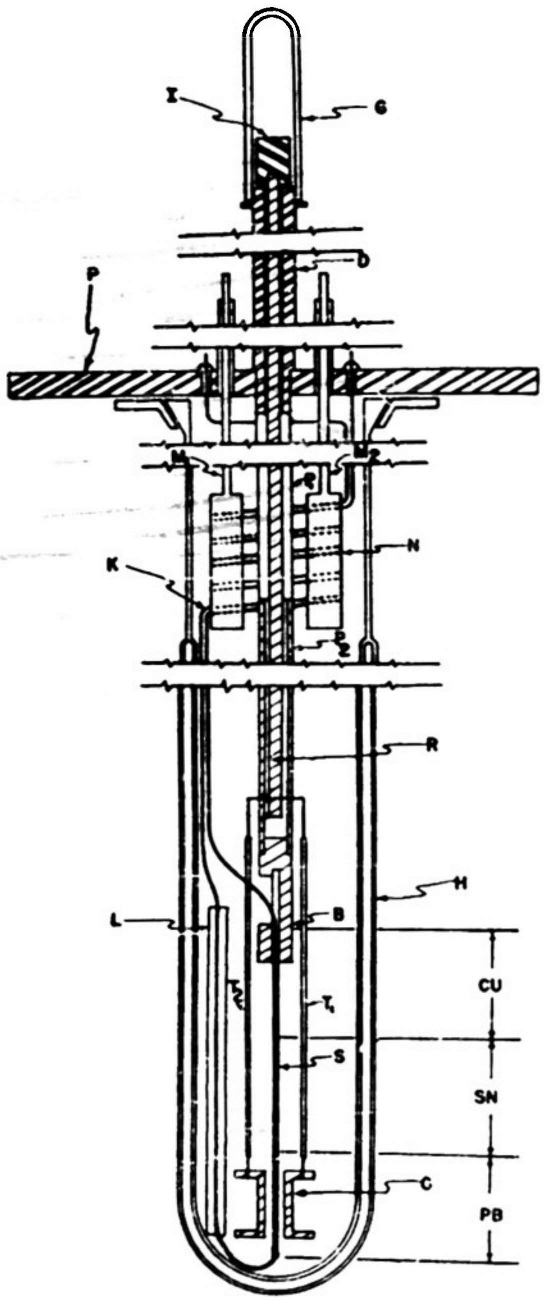

FIG. 2. Schematic cross section of the experimental apparatus (not to scale).

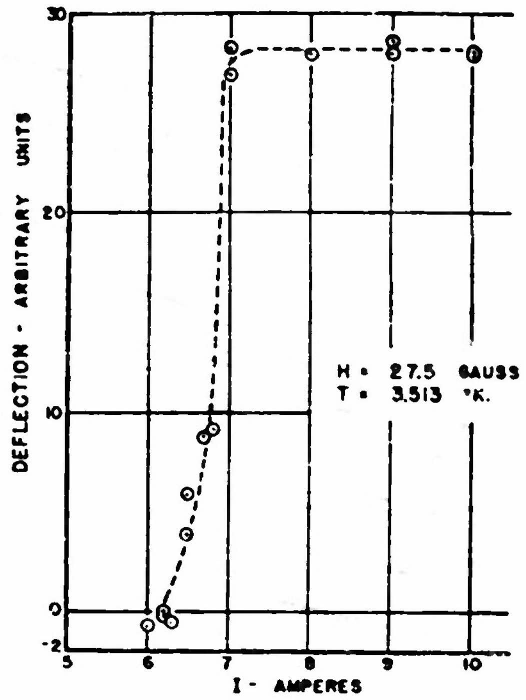

FIG. 3. Penetration of the T, H, I, surface at constant temperature and magnetic field.

from the upper plate, P, by steel and textolite pipes, P_1 and P_2, in series.

The coil is hung by means of two German silver tubes, T_1 and T_2, from a textolite rod, R. The rod R extends up through the pipes P_1 and P_2, and on through the plate and brass tube, D. Above the brass tube, the rod is fastened to an iron cylinder, I. The coil may be raised and lowered by moving the block of iron with a small solenoid placed on the outside of the glass vacuum cover, G.

To reduce heat leaks, a can for liquid nitrogen, N, is hung from the upper plate by two monel pipes, M_1 and M_2. The current carrying wires, K, leading to the sample are thermally connected to the liquid nitrogen can. The top of the copper cylinder is attached to one of the current leads; the return lead is shielded by a superconducting lead tube, so that its magnetic field cannot disturb the field at the specimen.

All of the apparatus shown in Fig. 2 is placed in a flask of liquid helium, H. Outside of this flask, and not shown, is an outer Dewar flask for liquid nitrogen. External to all this is the solenoid for producing vertical magnetic fields. The magnetic field produced by the external solenoid was known to be homogeneous, to within one percent, over the volume of the tin specimen. The temperature was measured and controlled by the vapor pressure of the helium bath, and the bath could be stirred by moving the coil up and down.

RESULTS

The experimental results are shown in Figs. 3, 4, and 5. In each of the figures, two of the three variables,

H, T, and I, were held constant while the third variable was changed in small steps. The abscissa is denoted by the parameter that was varied. The ordinate in the figure is the galvanometer ballistic throw obtained when the coil was taken from the center of the tin rod to the center of the lead rod.

The superconducting state could be destroyed in the tin by a sufficiently large current in the rod, by high enough temperatures, or by a sufficiently large external field. Under these conditions a large galvanometer deflection was obtained. The superconducting state could then be entered as shown by the arrows in the phase diagram of Fig. 1. Under these conditions the galvanometer deflection is reduced to zero, since both the tin and the lead are in the superconducting state. It is clear from the figures that the galvanometer deflection does not at any point increase in the direction of paramagnetism, i.e., showing greater flux in the tin specimen than normal. The scatter of the observed

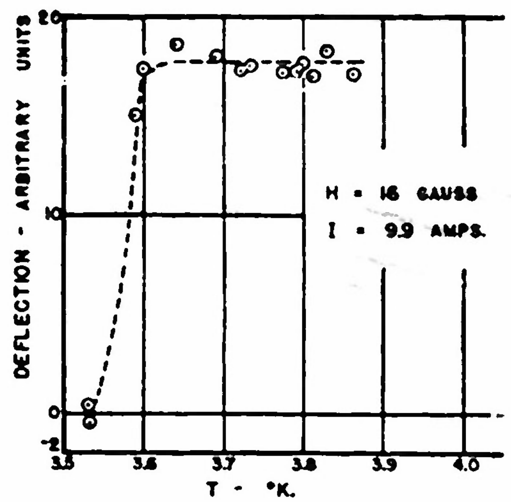

FIG. 4. Penetration of the T, H, I, surface at constant magnetic field and current.

deflections is fully explained by experimental error caused by uneven movement of the induction coil and small shifts in the galvanometer zero.

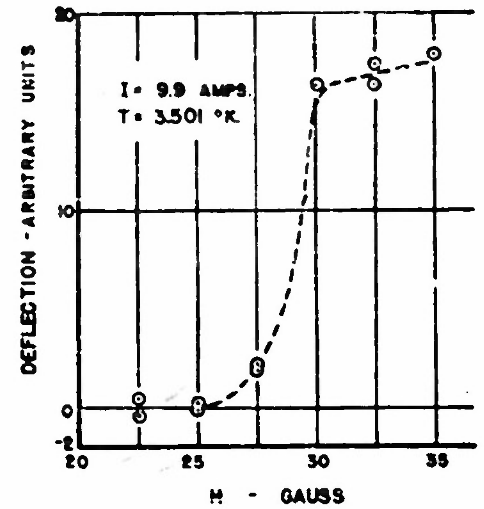

FIG. 5. Penetration of the T, H, I, surface at constant temperature and current.

CONCLUSIONS

Our results leave little doubt that, with the current of 10 amperes used in these experiments, there is no region in the H, T, I, space showing paramagnetic susceptibility. It must be emphasized that our findings are not necessarily in disagreement with the results of Meissner, Schmeissner, and Meissner, because the quantity measured is a different one in the two cases. In their work, the change in the magnetic induction produced by varying the external field is determined, and their observations, therefore, comprise the dynamics of the transition process. Our measurements, on the other hand, were carried out at a series of steady states in the $H-T-I$ space, well after any change in these parameters had taken place. Thus, we must conclude that such paramagnetic effects as have been observed with similar values of the parameters seem to be of a transient nature. They are, as was suggested earlier, possibly due to a re-arrangement of the magnetic flux when, in a cylinder carrying a current, additional currents are inducted in the specimen as it becomes superconducting in an external field.

It is hoped to extend the present work to higher values of the current.

Current Research

The Flow of Liquid Helium II Through Narrow Slits

A program of research to investigate some of the flow properties of liquid helium II was begun at this laboratory in the Spring of 1952, under the direction of visiting Professor K. Mendelssohn of the Clarendon Laboratory, Oxford. The work so far has been concentrated on the characteristics of flow through narrow slits under the influence of hydrostatic pressure gradients, using apparatus and techniques similar to those of Bowers and Mendelssohn.[1]

Although a great deal of research has already been done on this type of flow, starting with the thorough investigations of Allen and Misener[2], no work has been reported which employed pressure heads greater than a few centimeters of helium. In view of this, the present apparatus (see figure 1a) was designed so as to allow pressures corresponding to about 15 cm of helium to be obtained. The requisite quantity of liquid helium may be produced easily with a Collins liquifier, whereas such was not the case with the Linde liquifiers in use at Oxford and elsewhere.

The apparatus, shown in figure 1a, consists of a glass reservoir of 0.5 cm inside diameter attached to a flat glass plate. A second flat plate is placed at the bottom of the first, and the two plates are pressed together by means of the clamp and spring arrangement. In this way a circular channel having a quite uniform width of a few microns is obtained. The side or "static" tube opens into the flow channel so that a pressure measurement at an intermediate point in the slit may be made. The dimensions of the opening are such as to avoid a false pressure indication

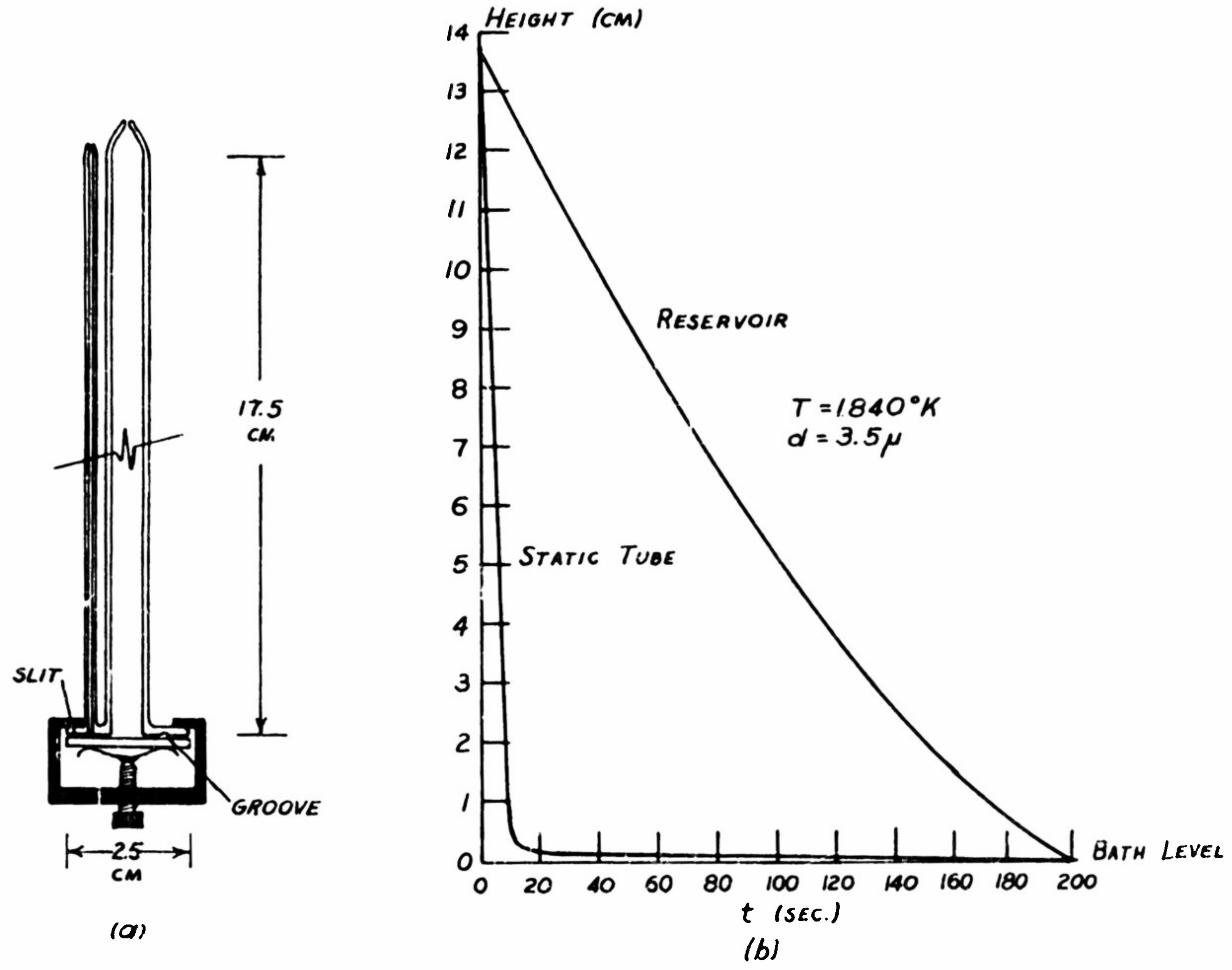
SLIT
GROOVE
17.5 CM.
2.5 CM
(a)
HEIGHT (CM)
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RESERVOIR
T = 1840°K
d = 3.5μ
STATIC TUBE
BATH LEVEL
0 20 40 60 80 100 120 140 160 180 200
t (SEC.)
(b)

FIGURE 1.

due to any Bernoulli force. The reservoir is placed in a holder which may be moved up or down from outside the dewar vessel containing the liquid helium. The experimental technique is then to record the height of the liquid in the reservoir as a function of time after the reservoir is either lifted above or pushed below the bath level. Illumination for these measurements is provided by six two-watt neon bulbs located about one meter from the dewar vessel.

In order to insure that the flow be isothermal, a small opening is left at the top of the reservoir so that any temperature differences due to the mechano-caloric effect are neutralized by thermal contact with the helium vapor. This opening at the top is small enough, however, to restrict the flow of helium film to a negligible amount. A carbon resistance thermometer placed in the reservoir has proved that the hole at the top is quite sufficient to provide temperature equalization. Furthermore, the actual rate of film flow was checked by experimentation with the slit purposely plugged with a silicone compound, and the contribution due to the film was found to be negligible at all temperatures and pressures. The width of the flow channel is determined by measuring the rate of flow of helium I through it. Since this flow is laminar, the simple geometry of the flow apparatus permits calculation of the slit width from the measured flow rate at a given pressure head. The viscosity of helium I is taken from the work of Bowers and Mendelssohn.[3]

The experimentally obtained curves of liquid height in the reservoir (relative to the bath level) versus time are fitted to a power series of the form

$$h = h_0 + a_1 t + a_2 t^2 + a_3 t^3$$

by the method of least squares. This expression is then differentiated and multiplied by the crossectional area of the reservoir to give the volume rate of flow. A typical curve of h vs. t is shown in figure 1b. It is to be noted that the pressure measured by the side tube falls very rapidly to the bath level, as in previous work at lower pressure heads[1,4]. This is interpreted to mean that the only pressure gradient in the channel is at its narrowest part, i.e. at the perimeter of the reservoir. The flow in the remainder of the channel thus takes place under an essentially zero pressure gradient and hence is frictionless superflow.

Figure 2 shows the results of a series of experiments with a slit width of $3.8\,\mu$, giving the flow rates as functions of pressure head at fixed temperatures. The linear flow rate given at the right in figure 2, is defined as the volume rate of flow divided by the crossectional area of the flow channel at the perimeter of the reservoir. This linear velocity of course decreases as $1/r$ along the radius of the flow channel. The most interesting result of these measurements is that the flow rate at a given temperature reaches a constant value, at a sufficiently high pressure head, dependent only on the temperature (and also probably on the channel width). In the previous work of this nature at lower pressure heads it was found that the flow rate was dependent on a power of the pressure head in the manner

$$\dot{V} = \text{constant}\ (\Delta p)^n$$

where n is essentially independent of temperature but dependent on

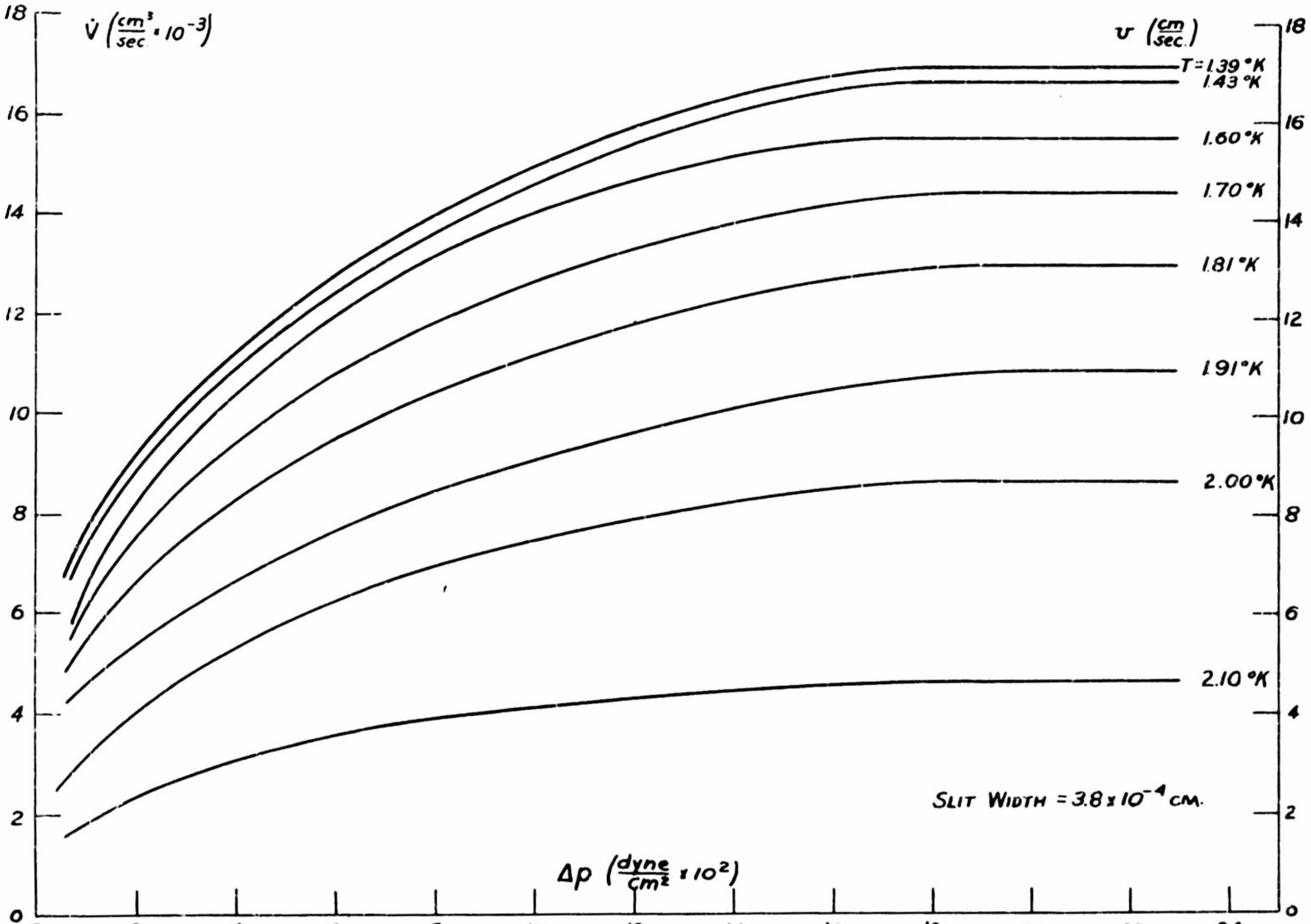

FIG. 2. FLOW RATE VS. PRESSURE

the slit width. In figure 3 the flow rate and pressure head are plotted logarithmically, and it is evident that such a relation is valid in these results, at the lower pressure. The value of n obtained for a 3.8 μ slit is n = 0.35, which is in general agreement with other work[1,2]. Bowers and Mendelssohn[1], using a 1.2 μ slit, found n to be equal to 0.27, and since n seems to increase with increasing slit width, the present value of 0.35 is quite plausible. Figure 4 shows the flow rates plotted against temperature for several values of the pressure head. Although, there does not seem to be any simple empirical relation between the flow rate and temperature, the curves are of the same general shape as has been obtained for film flow and for flow through capillaries.

At the present time we have no theoretical argument for the existence of these "saturation" velocities. However, it is of considerable interest to note that the linear saturation velocities are of the same magnitude as the critical velocities found in flow induced by a temperature gradient(see, for example, ref.1). It is possible that a further increase in the hydrostatic pressure head would eventually give higher flow velocities, and that the flow thus obtained would exhibit frictional dissipation, as is true of the super-critical flow under temperature gradients.

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* Magnolia Fellow

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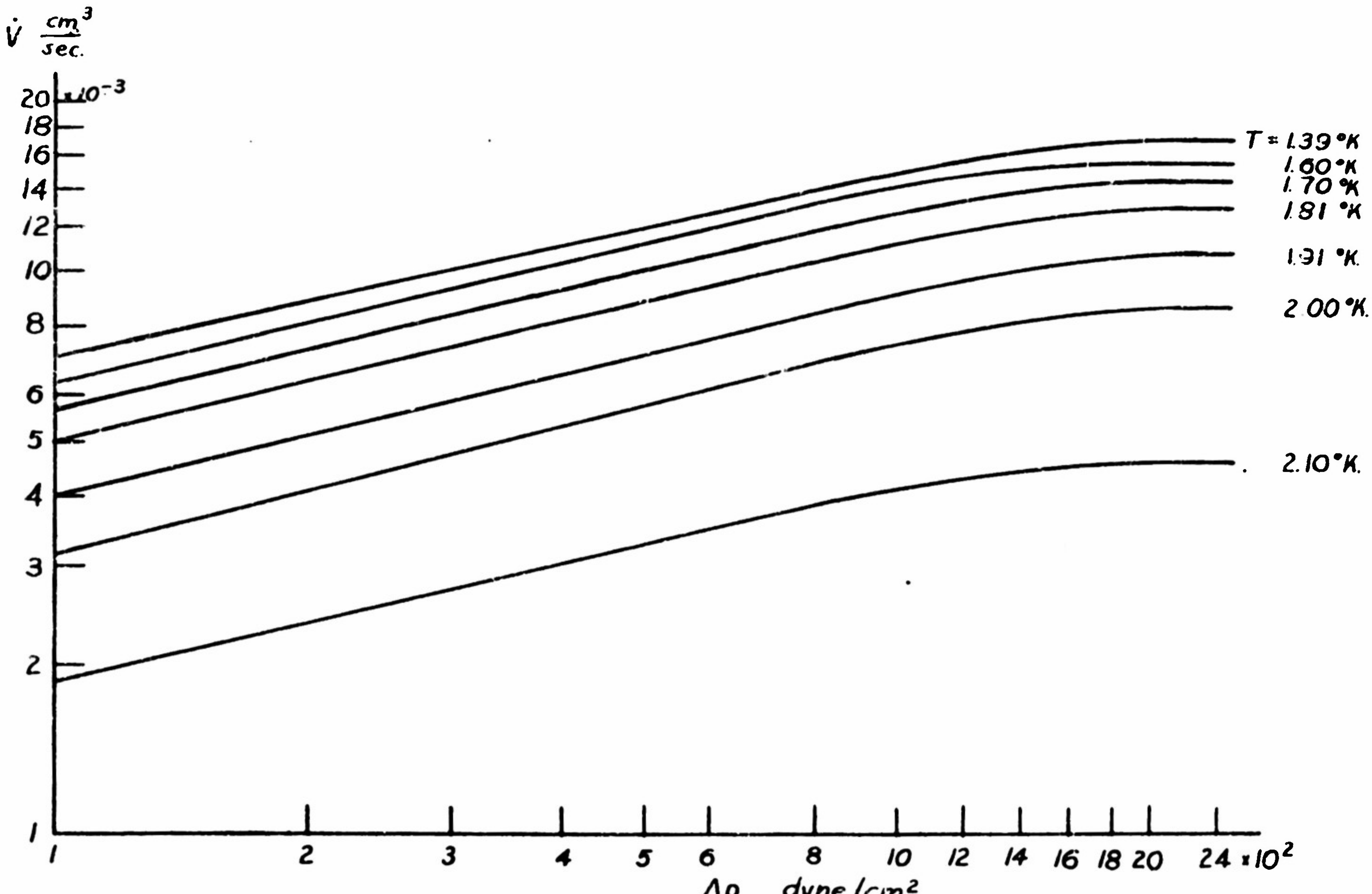

FIG. 3. PRESSURE DEPENDENCE OF HE II FLOW. SLIT WIDTH = 3.8×10^{-4} CM.

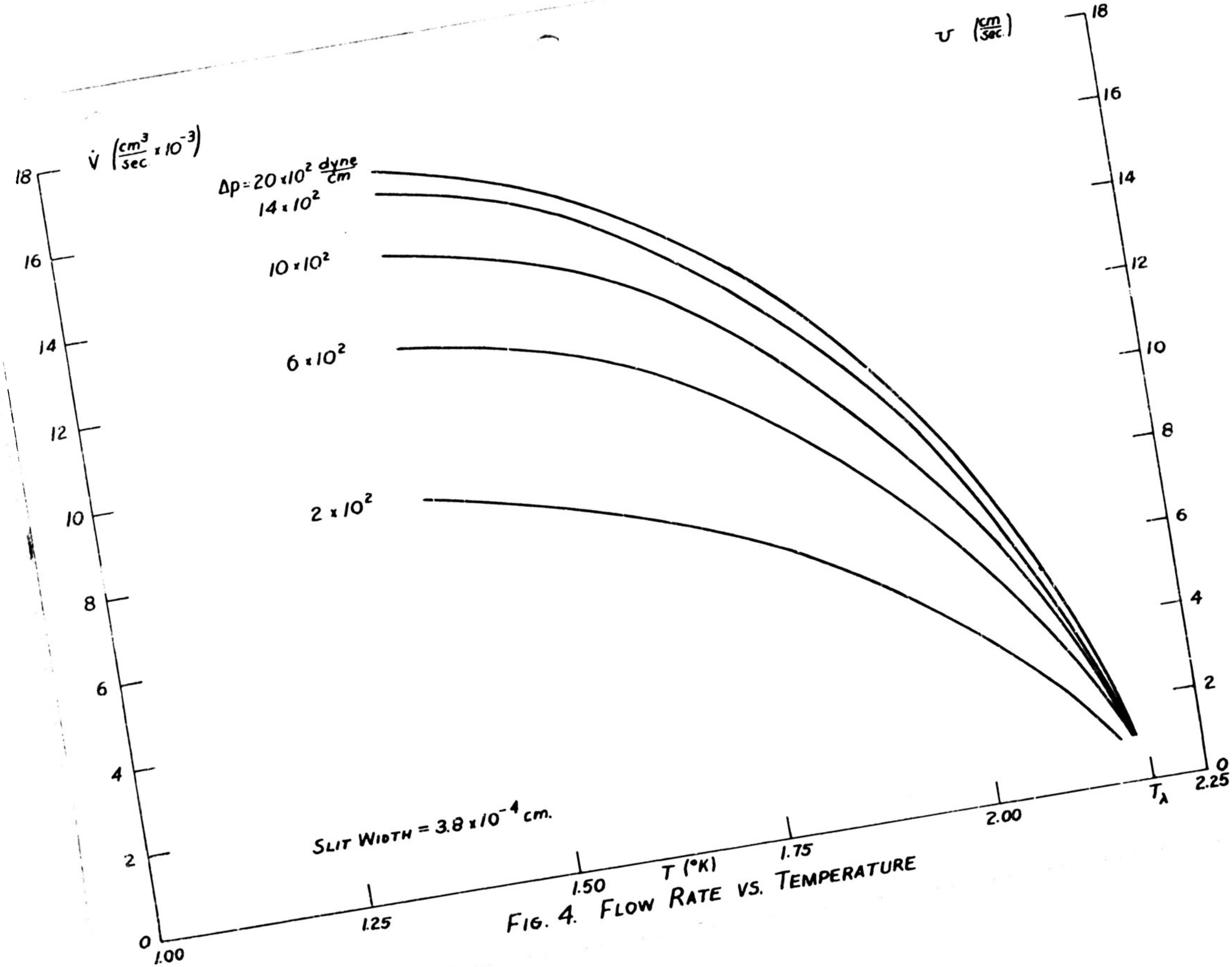

FIG. 4. FLOW RATE VS. TEMPERATURE

Ultrasonic Measurements on Potassium Chrome Alum

Investigations of potassium chrome alum by various methods in the liquid air temperature region have revealed the presence of some type of structural transition, having evidently a rather large hysteresis. So far the methods used have been paramagnetic relaxation experiments[1] and measurements of the dielectric constant[2]. Experiments have been undertaken in this laboratory to study this transition by means of the ultrasonic pulse technique, which measures the velocity of sound in a given direction. A sound wave is generated on one face of a large single crystal by means of a quartz transducer and is detected on the opposite face by a similar quartz crystal. Measurements made on rock salt agree with previous measurements[3]. Thus far, measurements of potassium chrome alum have been made from room temperature to 92°K, showing an increase in velocity of about 2%. Magnetic fields less than H = 2000 gauss appear to have no effect on the velocity. Great difficulties have been encountered in attaching the quartz transducers to the specimen at low temperatures, since in this range most binders used do not transmit sufficient energy to give a detectable pulse. It is planned to extend these measurements down to lower temperatures available with liquid air.

Philip Closmann

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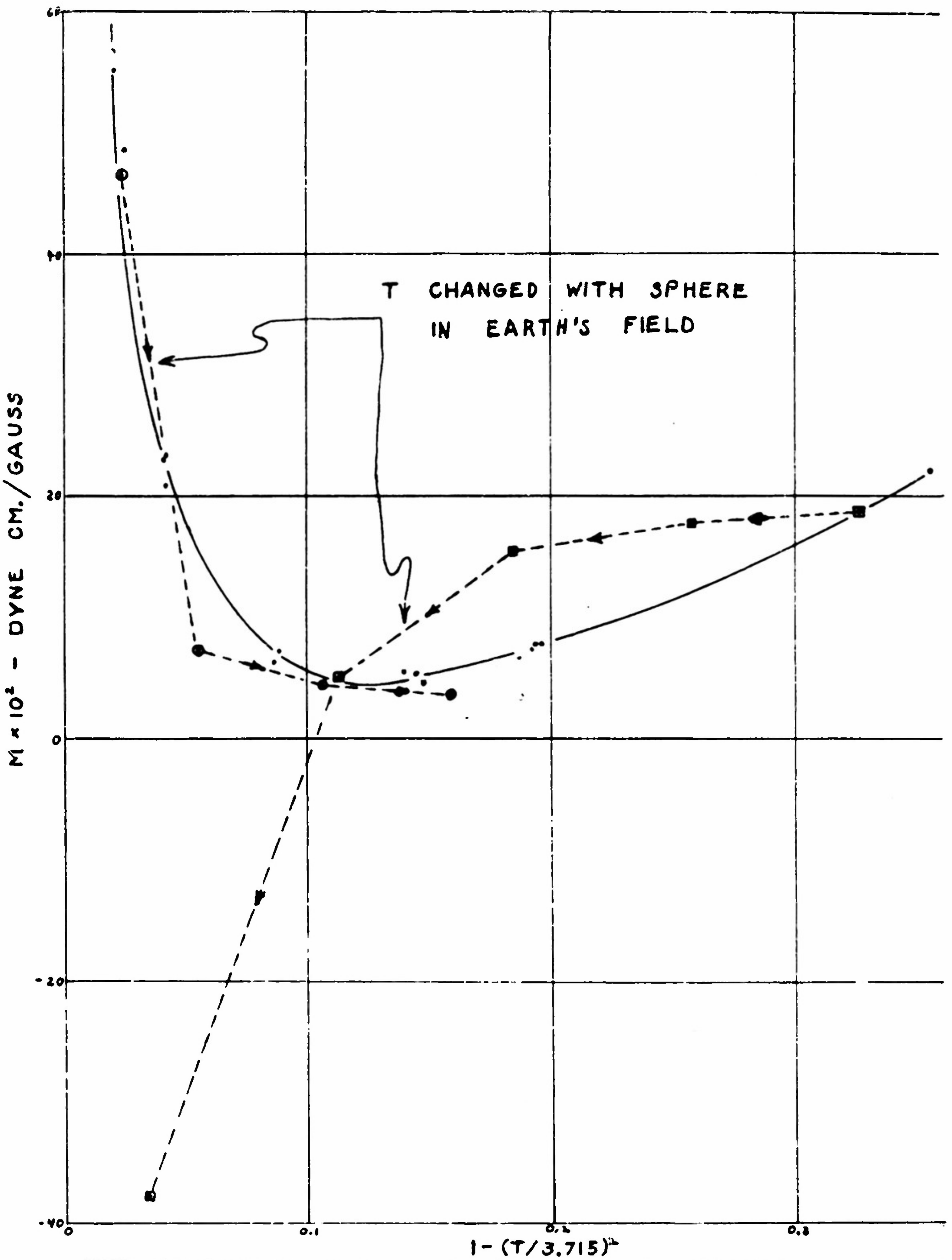

THE EFFECTIVE DIPOLE MOMENT AS A FUNCTION OF $B_c(T)/B_0$

Residual Flux in a Superconducting Sphere

The residual flux in a superconducting sphere is being studied by the torsion pendulum method. The experimental apparatus has been described previously[1]. The method consists in measuring the torque on the sphere as a function of an externally applied magnetic field. The geometry of the sphere and field is quite good, in that the diameter of the sphere is $1.0000 \pm .0004$ inches, and the field of the Helmholtz coils is homogeneous to within 0.1% over the volume of the sphere. The currents for producing the fields are taken from a bank of Edison cells and, for fields less than 10 gauss, the field may be held constant to within 0.004 gauss during any one measurement.

It is found that the torque, L, on the sphere (determined from period measurements) may be expressed as

$$L = \alpha + \beta B + \gamma B^2$$

where α, β, γ are constants and B is the "free stream" field of the coils. An effective magnetic dipole moment, M, for the sphere is defined as being proportional to β. The normal-superconducting transition may be made either by holding the temperature constant and reducing the magnetic field (the constant T method), or by holding the magnetic field constant and reducing the temperature (the constant H method). Preliminary results indicate the following:

Transition by the constant T method:

1. When M is measured at the temperature at which the normal-superconducting transition is made, then M plotted as a function of $B_c(T)$ gives a smooth, reproducible curve (see figure). The value of M as a function of $B_c(T)$ goes through a minimum at a temperature of

approximately $3.5^{o}K$.

2. When the temperature is changed, with the sphere as a whole remaining in the superconducting state, then for high temperatures the value of M changes. These changes appear to depend markedly on the external field (fields of 0.2 gauss cause large differences in behavior). There is not enough data to tell whether the changes are either reproducible or reversible.

3. When the temperature is raised above $3.5^{o}K$ the moment has been observed to reverse in direction and increase in magnitude in some instances. The conditions under which this reversal occurs have not been isolated as yet. A kind of Meshkovsky and Shalnikov experiment[2] is being prepared to see if this reversal of M corresponds to a reversal of the field lines in the sphere. The direction of the field will be determined by the Hall effect.

To our knowledge, neither the minimum nor the temperature variation of M has been reported previously.

4. We have obtained no B^2 coefficient of damping reported by other workers.[3]

Transition by the constant H method:

Very little data is available on these moments, but they appear to exhibit the same temperature variations as the constant T moments. Moreover, the moment seems to be independent of the field used to form M , and depends primarily on the temperature at which M is measured.

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Thermal Noise at Low Temperatures

In 1928, J. B. Johnson[1] announced that in a conductor there are random variations of potential of such magnitude that the mean square value contributed by the frequency range $\Delta \nu$ is

$$\bar{V}^2_{\Delta\nu} = 4 R k T \Delta \nu .$$

In the same issue of the Physical Review, H. Nyquist[2] derived this relationship using thermodynamic methods. Johnson tested this relationship using several different materials including electrolytic solutions. The lowest temperature used was approximately 70°K. D. A. Wilber[3] in 1932, did some more careful work on the subject in nearly the same temperature range. His work can be considered almost a precision determination of the Boltzmann constant k. Both of the experimenters found Nyquist's law valid in their range of investigation.

In 1911, Kamerlingh-Onnes discovered the phenomenon of superconductivity. In the superconducting state the resistance is rigorously zero. Therefore, by Nyquist's formula, the noise should go to zero. This suggests the problem of investigating the Johnson noise in a conductor as it passes into the superconducting state. However, before we can attack this problem, it will be necessary to develop equipment that will measure Johnson noise in the liquid helium region. Therefore, the first phase, and the phase presently engaged in, is to construct and test equipment which will measure the Johnson noise at low temperatures: first at nitrogen temperatures, and later at helium temperatures.

For the indicating device we are using a Tektronix 514-D oscilloscope. An Atomic Instrument Company linear amplifier, model 204 B, (A-1) is being used as a final amplifier.

The present work is to construct an intermediate amplifier to match the A-1 giving sufficient response to measure the Johnson noise at nitrogen temperatures when preceeded by a cathode follower input state. When this amplifier is complete, a "potted" two stage preamplifier is to be constructed and installed in the dewar. This type of installation is to be used because of the short leads to the test specimen which it will make possible.

We are attempting to use reasonably conventional circuits and components. To limit the shot noise and the noise generated by the plate resistors, smaller resistance values than the usual are being used in the earlier stages. 6AH6's are the tubes used in the intermediate amplifier with plans of using 404A's in the preamplifier. IRC type BW wire wound resistors are being used in many parts of the circuit since they have lower inherent noise than carbon resistors.

George Dalrymple

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2 H. Nyquist, Phys. Rev. 32, 110 (1928)

3 D. A. Wilbur, "Thermal Agitation of Electricity in Conductors", Dissertation, University of Michigan, 1932

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Paramagnetic Effect in the Transition Between Normal and Super-conductivity

A letter has been received from W. Meissner indicating that the negative results obtained in previous measurements[1] of the paramagnetic effect in superconduction are not inconsistent with the results of Meissner, Schmeissner and Meissner[2]. The experiments of ref.(1) were carried out in a region of H I T space exhibiting no paramagnetic effect. Meissner gives an expression which describes the upper boundary of this region:

$$I = I_g + \gamma DH$$

where I is the minimum current (in amp) in the sample for the effect to occur, γ is a parameter, D is the diameter of the specimen in mm, and H is the field (in oersted) (see Fig. 1). The original data are shown in Fig. 1 as X and all except one lie clearly within the region of no effect.

The apparatus has been altered in two respects: (1) a brass tube concentric with the specimen is used as the return current lead; (2) the current supplies are obtained from a bank of Edison cells. Measurements have been made using values of current and field which are decidedly within the region where the effect is expected. A temperature was chosen in which the superconducting transition occurred for a current of 11.5 amps in a magnetic field of 5 oersteds. (see 0 on Fig. 1) The transition to the superconducting state was made by changing the current. A pronounced increase in the flux through the specimen was obtained in the transition (Fig. 2). In the immediate neighborhood of the peak in the curve, the galvanometer shows spontaneous fluctuations of 5 to 10 mm.

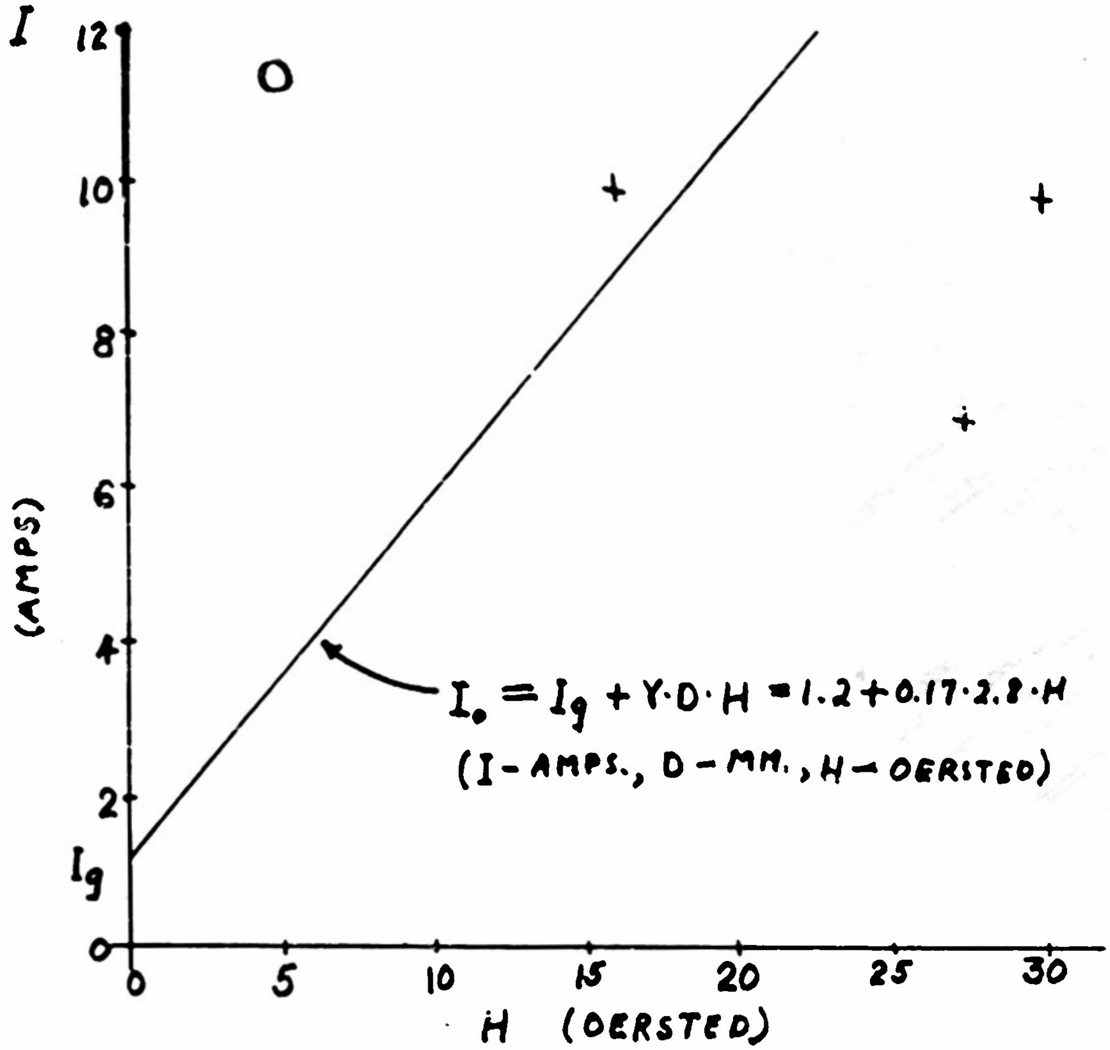

Fig 1 MINIMUM I VS. H FOR PARAMAGNETIC EFFECT

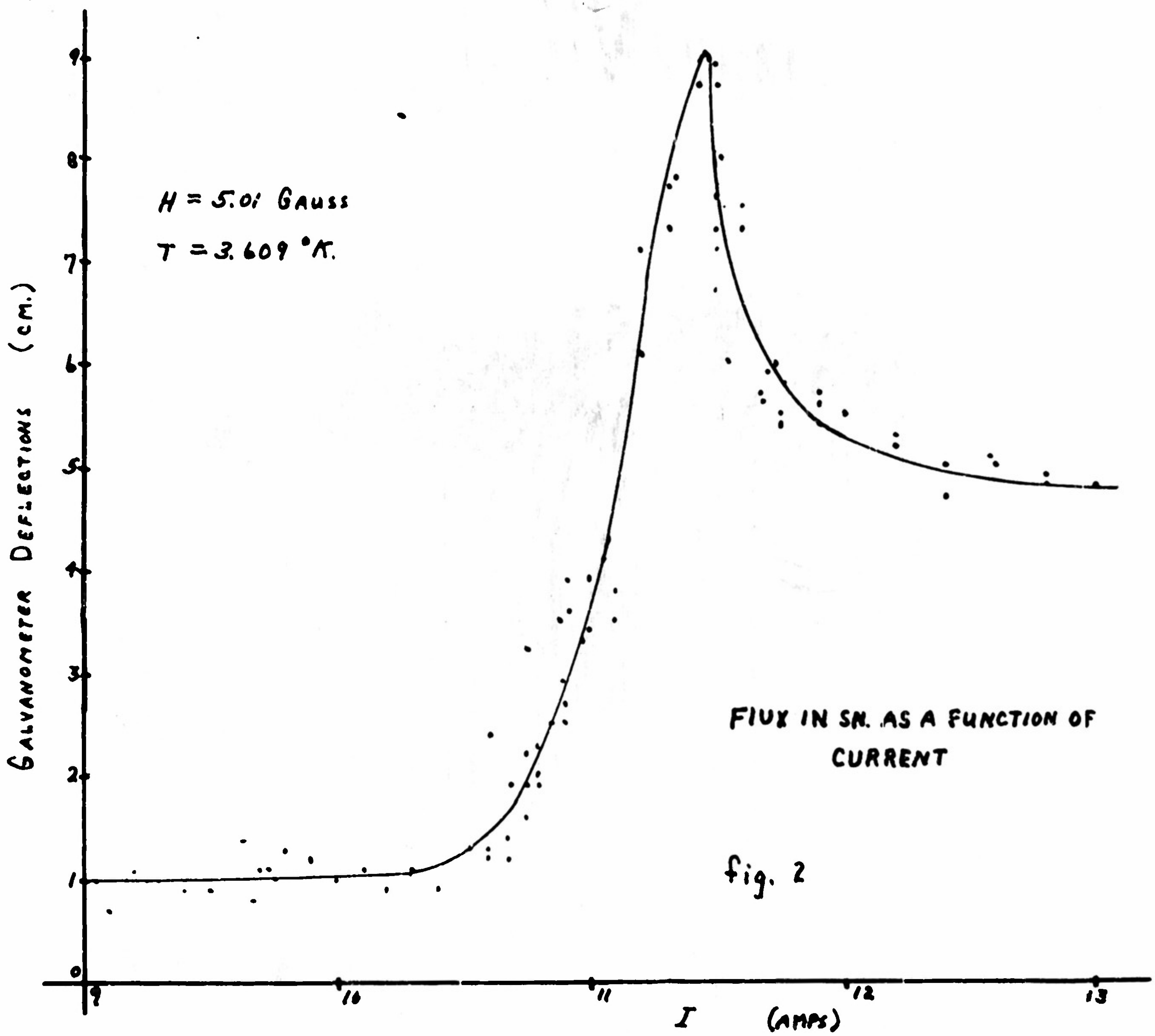
H = 5.01 Gauss
T = 3.609 °K.
Galvanometer Deflections (cm.)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
I (amps)
Flux in Sn. as a function of current

fig. 2

These random deflections appear when the coil is held stationary around the tin, and occur only near the peak of the curve.

Future experiments are planned to investigate the accuracy and sharpness of Meissner's curve, and to search for possible hysteresis in the paramagnetic increase.

James Thompson
Tom S. Teasdale

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[1] Mendelssohn, Squire and Teasdale, Phys. Rev. 87, 589 (1952)

[2] Meissner, Schmeissner and Meissner, Z. Physik, 130, 521 (1951); 130, 529 (1951); 132, 529 (1952).